



## NOAA SCIENTIFIC PUBLICATIONS REPORT OCTOBER 11, 2016

### **HIGHLIGHTED ARTICLES**

#### [Upward revision of global fossil fuel methane emissions based on isotope database](#)

Nature (38.138)

#### [Quantifying overlap between the Deepwater Horizon oil spill and predicted bluefin tuna spawning habitat in the Gulf of Mexico](#)

Scientific Reports (5.228)

#### [Characterizing loggerhead sea turtle, \*Caretta caretta\*, bycatch in the US shark bottom longline fishery](#)

Bulletin of Marine Science (1.503)

#### [Protozoal-related mortalities in endangered Hawaiian monk seals \*Neomonachus schauinslandi\*](#)

Diseases of Aquatic Organisms (1.586)

### **CROSS LINE OFFICE ARTICLES**

#### [Modeling connectivity of walleye pollock in the Gulf of Alaska: Are there any linkages to Bering Sea and Aleutian Islands?](#)

Deep Sea Research II (2.763)

#### [Timing of ice retreat alters seabird abundances and distributions in the southeast Bering Sea](#)

Biology Letters (3.248)

#### [Evaluation of morbillivirus exposure in cetaceans from the northern Gulf of Mexico 2010-2014](#)

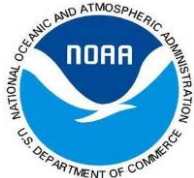
Endangered Species Research (1.81) -- Special Issue "Effects of the Deepwater Horizon oil spill on protected marine species."

### **ADDITIONAL ARTICLES**

#### [NMFS Publications](#)

#### [How old are you? Relative genet age estimates in a clonal animal](#)

Molecular Ecology (5.84)



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[Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish](#)  
ICES Journal of Marine Science (2.525)

[Biology and life history of green sturgeon \(\*Acipenser medirostris\*\): State of the science](#)  
Journal of Applied Ichthyology (0.783)

[Combining imperfect automated annotations of underwater images with human annotations to obtain precise and unbiased population estimates](#)  
Methods in Oceanography (1.90)

[Contrasting patterns in growth and survival of Central Valley fall run Chinook salmon related to hatchery and ocean conditions](#)  
Environmental Biology of Fishes (1.404)

[The origins and rise of shark biology in the 20<sup>th</sup> century](#)  
Marine Fisheries Review (1.25)

[Population dynamics and secondary production of juvenile white shrimp \(\*Litopenaeus setiferus\*\) along an estuarine salinity gradient](#)  
Fishery Bulletin (1.135)

### OAR Publications

[Gap winds and their effects on regional oceanography Part I: Cross Sound, Alaska](#)  
Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

[Gap winds and their effects on regional oceanography Part II: Kodiak Island, Alaska](#)  
Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

[Temporal variability of reactive iron over the Gulf of Alaska Shelf](#)  
Deep Sea Research Part II: Topical Studies in Oceanography (2.763)



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### Long-term observations of Alaska Coastal Current in the northern Gulf of Alaska

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

### Southeast Alaskan shelf from the southern tip of Baranof Island to Kayak Island: Currents, mixing and chlorophyll-a

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

### A model-based examination of multivariate physical modes in the Gulf of Alaska

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

### Spatial shifts in salmonine harvest, harvest rate, and effort by charter boat anglers in Lake Michigan, 1992–2012

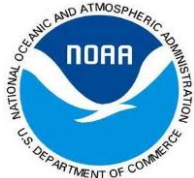
Journal of Great Lakes Research (1.77)

### Vertical air motions and raindrop size distributions estimated using mean doppler velocity difference from 3- and 35-GHz vertically pointing radars

IEEE Transactions of the Geoscience and Remote Sensing Society (2.228)

### Deep and abyssal ocean warming from 35 years of repeat hydrography

Geophysical Research Letters (4.99)



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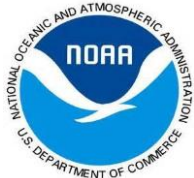
### HIGHLIGHTED ARTICLES

*Upward revision of global fossil fuel methane emissions based on isotope database*  
Nature (38.138)

**S. Schwietzke, O. A. Sherwood, L. M. P. Bruhwiler, J. B. Miller, G. Etiope, E. J. Dlugokencky, S. E. Michel, V. A. Arling, B. H. Vaughn, J. W. C. White, P. P. Tans (OAR/ESRL/GMD)**

- This study found that global fossil fuel methane emissions are larger than inventories calculate, but the amount of methane coming from leaking gas wells is getting lower over time.
- Specifically, the results show that methane emissions from fossil fuel sources are 1) are 60-110 percent higher than current estimates from emission inventories, but 2) are not increasing over time, although production has increased. The research also finds that natural gas methane emissions have declined from about 8 percent of production to about 2 percent of production over the past three decades.
- These results come from analysis of the largest isotopic source-signature database compiled to date.

Methane has the second-largest global radiative forcing impact of anthropogenic greenhouse gases after carbon dioxide, but our understanding of the global atmospheric methane budget is incomplete. The global fossil fuel industry (production and usage of natural gas, oil and coal) is thought to contribute 15 to 22 per cent of methane emissions to the total atmospheric methane budget. However, questions remain regarding methane emission trends as a result of fossil fuel industrial activity and the contribution to total methane emissions of sources from the fossil fuel industry and from natural geological seepage, which are often co-located. Here we re-evaluate the global methane budget and the contribution of the fossil fuel industry to methane emissions based on long-term global methane and methane carbon isotope records. We compile the largest isotopic methane source signature database so far, including fossil fuel, microbial and biomass-burning methane emission sources. We find that total fossil fuel methane emissions (fossil fuel industry plus natural geological seepage) are not increasing over time, but are 60 to 110 per cent greater than current estimates owing to large revisions in isotope source signatures. We show that this is consistent with the observed global latitudinal methane gradient. After accounting for natural geological methane seepage, we find that methane emissions from natural gas, oil and coal production and their usage are 20 to 60 per cent greater than inventories. Our findings imply a



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greater potential for the fossil fuel industry to mitigate anthropogenic climate forcing, but we also find that methane emissions from natural gas as a fraction of production have declined from approximately 8 per cent to approximately 2 per cent over the past three decades.

Publication Date: October 5, 2016

Available Online:

<http://www.nature.com/nature/journal/v538/n7623/full/nature19797.html>

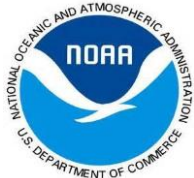
*Quantifying overlap between the Deepwater Horizon oil spill and predicted bluefin tuna spawning habitat in the Gulf of Mexico*

Scientific Reports (5.228)

**E. L. Hazen** (NMFS/SWFSC), **A. B. Carlisle** (NMFS/SWFSC), S. G. Wilson, J. E. Ganong, M. R. Castleton, R. J. Schallert, M. J. W. Stokesbury, **S. J. Bograd** (NMFS/SWFSC), B. A. Block

- Adult Atlantic bluefin tuna were oiled during the deepwater horizon leak, while transiting and spawning in the Gulf.
- Here we use a large tagging dataset to examine movement and residency within the Gulf, predicting weekly habitat and overlaying it with weekly oil extent.
- The oiling did not cover a large part of their habitat, but bluefin face are already stressed and continue to face multiple threats on their Gulf of Mexico spawning grounds.

Atlantic bluefin tuna (*Thunnus thynnus*) are distributed throughout the North Atlantic and are both economically valuable and heavily exploited. The fishery is currently managed as two spawning populations, with the GOM population being severely depleted for over 20 years. In April-August of 2010, the Deepwater Horizon oil spill released approximately 4 million barrels of oil into the GOM, with severe ecosystem and economic impacts. Acute oil exposure results in mortality of bluefin eggs and larvae, while chronic effects on spawning adults are less well understood. Here we used 16 years of electronic tagging data for 66 bluefin tuna to identify spawning events, to quantify habitat preferences, and to predict habitat use and oil exposure within Gulf of Mexico spawning grounds. More than 54,000 km<sup>2</sup> (5%) of predicted spawning habitat within the US EEZ was oiled during the week of peak oil dispersal, with potentially lethal effects on eggs and larvae. Although the oil spill overlapped with a relatively small portion of predicted spawning habitat, the cumulative impact from oil, ocean warming and



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bycatch mortality on GOM spawning grounds may result in significant effects for a population that shows little evidence of rebuilding.

Publication Date: September 22, 2016

Available Online: <http://www.nature.com/articles/srep33824>

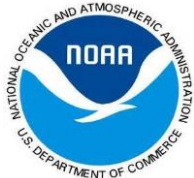
*Characterizing loggerhead sea turtle, *Caretta caretta*, bycatch in the US shark bottom longline fishery*

Bulletin of Marine Science (1.503)

**J. K. Carlson (NMFS/SEFSC), S. J. B. Gulak (NMFS/SEFSC), M. P. Enzenauer (NMFS/SEFSC), L. W. Stokes (NMFS/SEFSC), P. Richards (NMFS/SEFSC)**

- The authors used generalized linear models to determine which factors influence the probability of loggerhead sea turtle captures and at-vessel mortality in the shark bottom longline fishery
- Fishing method was not found to predict a capture of a sea turtle.
- A potential management action to reduce at-vessel sea turtle mortality would be to restrict soak times; circle hooks are unlikely to reduce mortality for bottom longlines due to the inability to surface for air

Sea turtle bycatch in longline fishing gear is an ongoing threat to the recovery of sea turtle populations. While considerable research has focused on pelagic longline fisheries, very little attention has been paid to captures of sea turtles in bottom longlines. Estimates of sea turtle takes in the shark bottom longline fishery have raised concern that this fishery may be impacting loggerhead sea turtle, *Caretta caretta*, populations. However, there are no current management actions designed to reduce the bycatch of sea turtles that target sharks using bottom longline gear because no studies have identified which factors, if any, influence the capture of a loggerhead sea turtle. We used generalized linear models to determine which factors influence the probability of loggerhead sea turtle captures in the shark bottom longline fishery, and which factors are related to at-vessel mortality. While a variety of fishing techniques were considered as factors, no particular fishing method was found to predict a capture of a sea turtle. The most significant factor in predicting the capture of a loggerhead sea turtle in shark bottom longline gear was the area fished. Soak time was found to predict at-vessel hooking mortality with the median time for a mortality to occur was 14-15 hrs. While no definitive fishing factor was identified in the capture or mortality of a loggerhead sea turtle, research is needed using controlled methods for further examining the factors affecting captures of sea turtles in this and other bottom longline fisheries.



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Acceptance date: September 14, 2016

*Protozoal-related mortalities in endangered Hawaiian monk seals* *Neomonachus schauinslandi*

Diseases of Aquatic Organisms (1.586)

**M. M. Barbieri (NMFS/PIFSC)**, L. Kashinsky, D. S. Rotstein, K. M. Colegrove, K. H. Haman, S. L. Magargal, A. R. Sweeny, A. C. Kaufman, M. E. Grigg, **C. L. Littnan (NMFS/PIFSC)**

- This study establishes a case definition for monk seal mortalities from protozoal infections, specifically toxoplasmosis. Case definitions provide a structured framework which we will use to classify future mortalities and communicate that to managers, scientists and the broader community.
- It provides managers and policy makers with peer-reviewed data to show that terrestrially-sourced pathogens (eg, *Toxoplasma gondii*) are a threat to this endangered species that warrants further attention.
- It provides transparency for the interested public and other stakeholders by comprehensively describing diagnostic findings related to all mortalities of monk seals from protozoal infections.

Protozoal infections have been widely documented in marine mammals and may cause morbidity and mortality at levels that result in population level effects. The presence and potential impact on the recovery of endangered Hawaiian monk seals *Neomonachus schauinslandi* by protozoal pathogens was first identified in the carcass of a stranded adult male with disseminated toxoplasmosis and a captive monk seal with hepatitis. We report 7 additional cases and 2 suspect cases of protozoal-related mortality in Hawaiian monk seals between 2001 and 2015, including the first record of vertical transmission in this species. This study establishes case definitions for classification of protozoal infections in Hawaiian monk seals. Histopathology and immunohistochemistry were the primary diagnostic modalities used to define cases, given that these analyses establish a direct link between disease and pathogen presence. Findings were supported by serology and molecular data when available. *Toxoplasma gondii* was the predominant apicomplexan parasite identified and was associated with 100% of mortalities (n = 8) and 50% of suspect cases (n = 2). Incidental identification of sarcocysts in the skeletal muscle without tissue inflammation occurred in 4 seals, including one co-infected with *T. gondii*. In 2015, 2 cases of toxoplasmosis were identified ante-mortem and shared similar clinical findings, including hematological abnormalities and histopathology. Protozoal-related mortalities,





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specifically due to toxoplasmosis, are emerging as a threat to the recovery of this endangered pinniped and other native Hawaiian taxa. By establishing case definitions, this study provides a foundation for measuring the impact of these diseases on Hawaiian monk seals.

Publication Date: September 26, 2016

Available Online: <http://www.int-res.com/abstracts/dao/v121/n2/p85-95/>

### CROSS LINE OFFICE ARTICLES

*Modeling connectivity of walleye pollock in the Gulf of Alaska: Are there any linkages to Bering Sea and Aleutian Islands?*

Deep Sea Research II (2.763)

C. Parada, **S. Hinckley (Fisheries-AFSC)**, J. Horne, M. Mazur, **A. J. Hermann (OAR-PMEL)**, E. Curchister

- Studied walleye pollock connectivity between the Gulf of Alaska and the Bering Sea and Aleutian Islands
- Used spatially-explicit individual-based model coupled to hydrodynamic model that simulates life history from eggs to age-0 juveniles
- Results found link between Shelikof Strait spawning and Shumagin nursery areas; Bering Strait important potential nursery area for Gulf of Alaska

We investigated the connectivity of walleye pollock in the Gulf of Alaska (GOA) and linkages to the Bering Sea (BS) and Aleutian Island (AL) regions. We used a spatially-explicit Individual-based model (IBM) coupled to 6 years of a hydrodynamic model that simulates the early life history of walleye pollock in the GOA (eggs to age-0 juveniles). The processes modeled included growth, movement, mortality, feeding and the bioenergetics component for larvae and juveniles. Simulations were set to release particles on the 1st of the month (February to May) in fourteen historical spawning areas in the GOA up to the 1st of September each year. Model results reproduced the link between the Shelikof Strait spawning area and the Shumagin nursery region for March and April spawners, besides other Potential Nursery Areas (PNAs) found in the GOA. A prominent finding of this study was the appearance of the BS as important PNAs for several GOA spawning grounds, which is supported by a consistent flow into the BS through Unimak Pass. The simulations showed the highest density of simulated surviving pollock in the western Bering Sea (WBS) region with the lowest coefficients of variation of the whole domain. Three spawning sectors were defined, which aggregate multiple spawning areas in the eastern (EGOA), central





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(CGOA) and western Gulf of Alaska (WGOA). A connectivity matrix showed strong retention within the CGOA (25.9%) and EGOA (23.8%), but not in the WGOA (7.2%). Within the GOA, the highest connectivity is observed from EGOA to CGOA (57.8%) followed by the connection from CGOA to WGOA (24.3%). Overall, one of the most prominent connections was from WGOA to WBS (62.8%), followed by a connection from CGOA to WBS (29.2%). In addition, scenarios of shifting spawning locations and nursery sectors of GOA, BS and AL are explored and implications for walleye pollock stock structure hypotheses are discussed.

Published: October, 2016

Available Online:

<http://www.sciencedirect.com/science/article/pii/S0967064515004415>

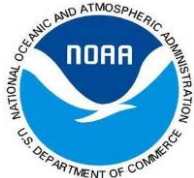
### *Timing of ice retreat alters seabird abundances and distributions in the southeast Bering Sea*

Biology Letters (3.248)

**M. Renner, S. Salo (OAR/PMEL), L. B. Eisner (NMFS/AFSC), P. H. Ressler (NMFS/AFSC), C. Ladd (OAR/PMEL), K. J. Kuletz, J. A. Santora, J. F. Piatt, G. S. Drew, G. L. Hunt**

- This study looks at the impact of the timing of spring sea-ice retreat on southeast Bering Sea food web
- Results suggest a mechanistic understanding of how present and future changes in sea-ice-retreat timing may affect top predators like seabirds in the southeastern Bering Sea

Timing of spring sea-ice retreat shapes the southeast Bering Sea food web. We compared summer seabird densities and average bathymetry depth distributions between years with early (typically warm) and late (typically cold) ice retreat. Averaged over all seabird species, densities in early-ice-retreat-years were 10.1% (95% CI: 1.1–47.9%) of that in late-ice-retreat-years. In early-ice-retreat-years, surface-foraging species had increased numbers over the middle shelf (50–150 m) and reduced numbers over the shelf slope (200–500 m). Pursuit-diving seabirds showed a less clear trend. Euphausiids and the copepod *Calanus marshallae/glacialis* were 2.4 and 18.1 times less abundant in early-ice-retreat-years, respectively, whereas age-0 walleye pollock *Gadus chalcogrammus* near-surface densities were 51× higher in early-ice-retreat-years. Our results suggest a mechanistic understanding of how present and future changes in sea-ice-retreat timing may affect top predators like seabirds in the southeastern Bering Sea.



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Publication Date: September 20, 2016

Available Online: <http://rsbl.royalsocietypublishing.org/content/12/9/20160276>

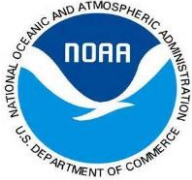
### *Evaluation of morbillivirus exposure in cetaceans from the northern Gulf of Mexico 2010-2014*

Endangered Species Research (1.81) -- Special Issue "Effects of the Deepwater Horizon oil spill on protected marine species."

**D. A. Fauquier (NMFS/OPR), J. Litz (NMFS/SEFSC), S. Sanchez, K. Colegrove, L. H. Schwacke (NOS), L. Hart, J. Saliki, C. Smith, T. Goldstein, S. Bowen-Stevens (NMFS/SEFSC), W. McFee (NOS), E. Fougères (NMFS/SERO), B. Mase-Guthrie (NMFS/SEFSC), E. Stratton (NMFS/SEFSC), R. Ewing (NMFS/SEFSC), S. Venn-Watson, R. H. Carmichael, C. Clemons-Chevis, W. Hatchett, D. Shannon, S. Shippee, S. Smith, L. Staggs, M. C. Tumlin, N. L. Wingers and T. K. Rowles (NMFS/OPR)**

- The current study demonstrated that morbillivirus infections occurred infrequently and were not a leading cause of death of cetaceans sampled between February 2010 and July 2014 or a cause of the GOMx unusual mortality event (UME).
- Additionally, the partial and whole genome sequencing work confirmed that the current GOMx morbillivirus is distinct from the isolate found in cetaceans dying during the outbreak from 2013-2015 in the U.S. mid-Atlantic.
- Interestingly, this study's detection of what appears to be sporadic or episodic morbillivirus infections in younger GOMx bottlenose dolphins supports the hypothesis that dolphin morbillivirus is endemic in the region and successfully persisting in some offshore small cetacean populations in the GOMx.

The potential role of morbillivirus was evaluated in the deaths of >1100 bottlenose dolphins (*Tursiops truncatus*) and other small cetaceans that stranded from February 2010 through July 2014, during the northern Gulf of Mexico (GOMx) unusual mortality event (UME). 142 live or fresh-dead cetaceans were selected for morbillivirus analysis, and results were combined with samples from 102 live, free-ranging bottlenose dolphins sampled during capture-release health assessments conducted from 2011-2014. Polymerase chain reaction (PCR) testing for morbillivirus was performed; 9.9% (14/142) of the stranded cetaceans and 1% (1/83) of the free-ranging live dolphins were positive for dolphin morbilliviral (DMV) RNA. In contrast, previous DMV dolphin die-offs had detectable DMV by



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PCR in 61% to 97% of animals tested. Histologic findings consistent with morbillivirus infection, including lymphoid depletion, bronchointerstitial pneumonia, syncytial cell formation, or meningoencephalitis, were found in 6.6% (9/136) of the cetaceans that had histologic examinations. Serological analysis using a virus neutralization assay detected 29% (5/17) of live stranded and 23% (23/102) of live free-ranging bottlenose dolphins had titers of 64 or greater for cetacean morbillivirus, indicating prior but not necessarily recent exposure to morbillivirus. Current findings suggest that DMV infection, although present in the northern GOMx, was sporadic and occurred at low levels and therefore was not the primary cause of the northern GOMx UME. Confirmation of DMV infections and existing DMV titers demonstrate continued exposure to morbillivirus among northern GOMx cetaceans since the first detection of this virus in the early 1990s. Acceptance Date: September 15, 2016

### ADDITIONAL ARTICLES

#### NMFS Publications

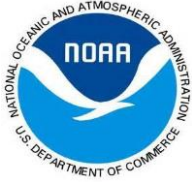
*How old are you? Relative genet age estimates in a clonal animal*

Molecular Ecology (5.84)

M. Devlin-Durante, **M. W. Miller (SEFSC/Miami)**, W. F. Precht, I. B. Baums

- Analyses based on somatic mutations in ESA-listed elkhorn coral, *Acropora palmata*, suggest that genetic individuals are centuries to millennia old.
- The oldest genetic individual was sampled in the Florida Keys.
- Old age implies a high degree of tolerance of past environmental change, whereas recent and ongoing population declines in this area suggest this broad environmental tolerance is now being exceeded.

Foundation species such as redwoods, seagrasses and corals are often long-lived and clonal. Genets may consist of hundreds of members (ramets) and originated hundreds to thousands of years ago. As climate change and other stressors exert selection pressure on species, the demography of populations change. Yet, because size does not indicate age in clonal organisms, demographic models are missing data necessary to predict the resilience of many foundation species. Here, we correlate somatic mutations with genet age of corals and provide the first, preliminary estimates of genet age in a colonial animal. We observed somatic mutations at 5 microsatellite loci in range wide samples of the endangered coral, *Acropora palmata* (n=3352). Colonies harbored 342 unique mutations in 147 genets. Genet age ranged from 30-838 years old (y/o) assuming a mutation rate of



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1.195-04 locus-1 year-1 based on colony growth rates and 236-6500 y/o assuming a mutation rate of 1.542-05 locus-1 year-1 based on sea level changes to habitat availability. Long-lived *A. palmata* genets imply a large capacity to tolerate past environmental change and yet recent mass mortality events in *A. palmata* suggest that capacity is now being frequently exceeded.

Acceptance Date: September 19, 2016

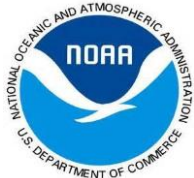
*Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish*

ICES Journal of Marine Science (2.525)

L. Kerr, N. Hintzen, S. Cadrin, L. Clausen, M. Dickey-Collas, **D. Goethel**, (NMFS/SEFSC), E. Hatfield, J. Kritzer, R. Nash

- Results suggest that even when population structure and management (or assessment units) mismatches occur, complete realignment of stock boundaries is not necessarily required for successful fisheries management. However, the utility of approaches varies on a continuum and there is typically a tradeoff between conservation and utilization goals.
- Successful application of the methods investigated and, ultimately, implementation of sustainable management requires that management bodies remain flexible and adaptive, which requires a quick response when new information on complex spatial population structure becomes available.
- Our results provide a synthesis of methods that will be useful for management bodies when attempting to deal with new information on a species spatial population structure. The results support the growing literature that suggests adaptive management is critical to maintaining sustainable fisheries, and that ignorance of spatial population structure can lead to localized depletion and impede stock rebuilding.

Recent advances in the application of stock identification methods have revealed inconsistencies between the spatial structure of biological populations and the definition of stock units used in assessment and management. From a fisheries management perspective, stocks are typically assumed to be discrete units with homogeneous vital rates that can be exploited independently of each other. However, the unit stock assumption is often violated leading to spatial mismatches that can bias stock assessment and impede sustainable fisheries management. The primary ecological concern is the potential for overexploitation of unique spawning components, which can lead to loss of productivity and reduced biodiversity along with destabilization of local and regional stock dynamics.



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Furthermore, ignoring complex population structure and stock connectivity can lead to misperception of the magnitude of fish productivity, which can translate to suboptimal utilization of the resource. We describe approaches that are currently being applied to improve the assessment and management process for marine fish in situations where complex spatial structure has led to an observed mismatch between the scale of biological populations and spatially-defined stock units. The approaches include: I) status quo management, II) 'weakest link' management, III) spatial and temporal closures, IV) stock composition analysis, and V) alteration of stock boundaries. We highlight case studies in the North Atlantic that illustrate each approach and synthesize the lessons learned from these real-world applications. Alignment of biological and management units requires continual monitoring through the application of stock identification methods in conjunction with responsive management to preserve biocomplexity and the natural stability and resilience of fish species.

Acceptance Date: September 18, 2016

*Biology and life history of green sturgeon (Acipenser medirostris): state of the science*

Journal of Applied Ichthyology (0.783)

**M. L. Moser (NMFS/NWFSC), J. A. Israel, M. Neuman (NMFS/WCRO), S. T. Lindley (NMFS/SWFSC), D. L. Erickson, B. W. McCovey, Jr., A. P. Klimley**

- This paper reviews current scientific knowledge of green sturgeon.
- The long marine occupancy of green sturgeon potentially exposes them to mortality from various human activities but also provides a theoretical reservoir of fish to support viable populations.
- Critically-needed information for protection of this species includes: accurate annual population size estimates, data on distribution and habitat requirements for larvae and juveniles, and assessment of mortality due to bycatch, poaching and marine mammal predation.

Green Sturgeon (GRS) *Acipenser medirostris* is one of the most marine-oriented of all sturgeons. It primarily spawns in the Sacramento, Klamath, and Rogue Rivers, yet lives most of its life in estuarine and coastal waters along the West Coast of North America. Spawning is only known to occur in the Rogue, Klamath and Sacramento rivers and optimal temperatures for egg incubation and larval growth are not always maintained in these dammed and highly-regulated systems. Genetic analysis and acoustic telemetry have confirmed the presence of two genetically distinct populations; the southern population is listed as "threatened" under the





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ESA. Adults only enter natal rivers to spawn every 1-4 yrs. They make extensive coastal migrations in depths < 80 m and move between estuaries where they aggregate in summer. The long marine occupancy of GRS potentially exposes them to mortality from various marine activities such as bottom trawl fishing, dredging, and ocean energy projects, but also provides a theoretical reservoir of fish to support viable populations. Critically-needed information for protection of this species includes: accurate annual population size estimates, data on distribution and habitat requirements for larvae and juveniles, and assessment of mortality due to bycatch, poaching and marine mammal predation.

Acceptance Date: September 22, 2016

*Combining imperfect automated annotations of underwater images with human annotations to obtain precise and unbiased population estimates*

Methods in Oceanography (1.90)

**J. H. Chang (NMFS/NEFSC), D. R. Hart (NMFS/NEFSC), B. V. Shank (NMFS/NEFSC), S. M. Gallagher, P. Honig, A. D. York**

- Provides and analyzes methods to combine automated and manual annotations of underwater images. This may reduce the amount of labor required to analyze large datasets of underwater imagery

Optical methods for surveying populations are becoming increasingly popular. These methods often produce hundreds of thousands to millions of images, making it impractical to analyze all the images manually by human annotators. Computer vision software can rapidly annotate these images, but their error rates are often substantial, vary spatially and are autocorrelated. Hence, population estimates based on the raw computer automated counts can be seriously biased. We evaluated four estimators that combine automated annotations of all the images with manual annotations from a random sample to obtain (approximately) unbiased population estimates, namely: ratio, offset, and linear regression estimators as well as the mean of the manual annotations only. Each of these estimators was applied either globally or locally (i.e., either all data were used or only those near the point in question, to take into account spatial variability and autocorrelation in error rates). We also investigated a simple stratification scheme that splits the images into two strata, based on whether the automated annotator detected no targets or at least one target. The 16 methods resulting from a combination of four estimators, global or local estimation, and one stratum or two strata, were evaluated using simulations and field data. Our results indicated that the probability of a false negative is the key factor determining the best method, regardless of the





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probability of false positives. Stratification was the most effective method in improving the accuracy and precision of the estimates, provided the false negative rate was not too high. If the probability of false negatives are low, stratified estimation with the local ratio estimator or local regression (essentially geographically weighted regression) are best. If the probability of false negatives are high, no stratification with a simple global linear regression or simply the manual sample mean alone is recommended.

Acceptance Date: September 19, 2016

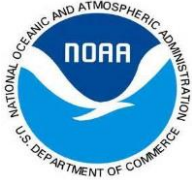
### *Contrasting patterns in growth and survival of Central Valley fall run Chinook salmon related to hatchery and ocean conditions*

Environmental Biology of Fishes (1.404)

**M. C. Sabal (NMFS/SWFSC), D. D. Huff (NMFS/NWFSC), M. J. Henderson, J. Fiechter, J. A. Harding (NMFS/SWFSC), S. A. Hayes (NMFS/NEFSC)**

- Relaxation events may be important for juvenile salmon growth and survival
- Size-selective mortality or density-dependence may be a strong influence affecting juvenile salmon survival

The objective of this study was to determine important ocean and hatchery covariates influencing early growth and survival of Central Valley fall run Chinook salmon. We used a dataset of recaptured coded wire tagged hatchery Chinook salmon to estimate early growth and cohort survival. Ocean conditions during the period of early ocean entry were based on output from a coupled physical-biogeochemical model configured for the broader California Current region. We built generalized additive and generalized linear models to describe growth and survival and used Akaike Information Criterion (AICc) model selection to determine which hatchery and ocean covariates related best to response variables. With regards to hatchery covariates, growth was best explained by release location, while survival was best explained by release weight and hatchery of origin. The ocean conditions included in the best models for both growth and survival included diatoms, predatory zooplankton, temperature, and currents. We observed the highest rates of salmon survival when in situ physical ocean conditions were indicative of relaxation events. For all four ocean covariates, the response curves illustrated opposite patterns between growth and survival models. This result implies that during periods of low survival, juvenile salmon were either 1) growing at a faster rate, or 2) growth appeared to increase because smaller fish had a higher mortality rate than larger fish. The first explanation would imply density-dependence, whereas the second explanation would imply size-selective mortality.



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These alternatives have implications on hatchery practices including salmon size at release and number of salmon in release groups.

Acceptance Date: September 14, 2016

### *The origins and rise of shark biology in the 20<sup>th</sup> century*

Marine Fisheries Review (1.25)

#### **J. I. Castro (NMFS/SEFSC)**

- Historical perspective of the development of the field, explanation for the extreme interest on sharks.
- Discussion on challenges to shark research owing to public perception of shark from movies such as “Jaws.”

Historically, the knowledge of sharks has always lagged far behind the knowledge of bony fishes and other vertebrates. In the 1950s, there were only a handful of researchers working or studying sharks. In the second half of the 20th century four factors combined to spark interest in sharks, make shark research feasible, and engender shark biology and shark conservation. These factors were: 1) Generous funding of research on shark attacks and the use of sharks for military purposes by the Office of Naval Research. 2) A rise in popularity of shark fishing and the development of marking tags that could be used to identify individual sharks. 3) The opening of China to commerce with the United States resulting in a new shark fishery in U.S. waters and active shark-fin markets. In turn, the rapid growth of the shark fin fishery and the geometric increase in the landings resulted in conservation concerns, and the eventual need for fishery regulations. 4) The release of the movie “Jaws” engendered a fear of sharks and started a shark killing craze that became an ecological disaster. “Jaws” affected the behavior and attitudes of millions of people towards sharks and the ocean, and the effects lasted for several decades. The effects of the movie were so deep, varied, and long-lasting that they eventually encompassed totally opposite behaviors. The most significant impact of the “Jaws” movie was caused by the character “Matt Hooper.” This character, and its personification, would have a profound and long-lasting effect on the young audience, for it told them that there was such a profession as shark biologist and that one could have a career studying sharks. Kids who saw the film often fantasized about being shark biologists. Unfortunately, the sad reality was that there were very few positions available in shark research. A common trait and peculiar aspect of many young people, who influenced by the movie “Jaws” wished to become shark biologists, was their general lack of interest in biology or natural history. This was surprising, because curiosity about animals or their



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natural history has always been the sine qua non of biologists. In a decade or two (~1995-2010), an unusual transformation occurred in the perception of sharks. In the society, sharks went from being feared animals to protected and even totemic animals. Totemism is a complex social phenomenon where individuals or groups form a mystical or emotional relationship with a venerated or sacred object, the totem, usually an animal. When sharks ceased to be fishes and became totemic animals, much of shark biology evolved into advocacy. Most of the logistical difficulties of the past are still with us, and shark research continues to be difficult. Today, much research is mainly concentrated on a few species of sharks, such as the totemic white shark and the “charismatic” whale shark.

Acceptance date: September 10, 2016

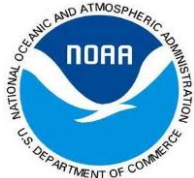
*Population dynamics and secondary production of juvenile white shrimp (Litopenaeus setiferus) along an estuarine salinity gradient*

Fishery Bulletin (1.135)

M. M. Mace III, **L. P. Rozas (NMFS/SEFSC)**

- This study incorporated a comprehensive evaluation of nursery habitat for juvenile white shrimp along an estuarine salinity gradient using estimates of density, biomass, growth, and secondary production as metrics;
- The saline and brackish habitats provided more important nursery habitat than the intermediate (oligohaline) habitat based on these metrics
- The relative value of nursery habitat can be dynamic, varying both spatially (within and among estuaries) and temporally.

We used estimates of shrimp density, growth, mortality, and secondary production for an 84-d sampling period to compare the value of nursery habitat for juvenile white shrimp (*Litopenaeus setiferus*) among 3 salinity zones (intermediate, brackish, and saline) within Sabine Lake, an estuary of the northern Gulf of Mexico. Density, growth, mortality, and secondary production were generally higher in the saline or brackish zones and lowest in the intermediate zone. The saline and brackish zones appeared to provide the most important nursery habitat on a per-area basis, but the intermediate zone also may contribute substantially to shrimp production because it encompasses a relatively large portion (26%) of coastal wetlands in Louisiana. The relative value of nursery areas can be dynamic with variation occurring both spatially (e.g., within an estuary and among estuaries) and temporally (e.g., from year to year). We documented within-estuary (i.e., among-salinity-zone) differences in the value of nursery habitat for white shrimp in Sabine Lake and expect this value, especially in the intermediate zone, to



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vary interannually. This dynamic nature of habitat value should be considered when assessing estuarine nursery areas.

Acceptance Date: September 26, 2016

### OAR Publications

*Gap winds and their effects on regional oceanography Part I: Cross Sound, Alaska*  
*Deep Sea Research Part II: Topical Studies in Oceanography (2.763)*

### **C. Ladd, W. Cheng (OAR/PMEL)**

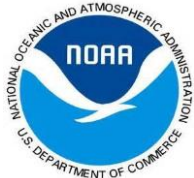
- This study reports on gap-wind events and their effects on ocean circulation patterns in the eastern Gulf of Alaska using observational data and model experiments.

Gap-wind events flowing from Cross Sound in the eastern Gulf of Alaska (GOA) were examined using QuikSCAT wind data. The average duration of an event is 3.6 days with the longest event recorded in the QuikSCAT dataset being 12 days. Daily offshore directed winds with speeds  $>10 \text{ m s}^{-1}$  are more common during the winter months (October–March), averaging 20.0 days per year, and less common during the summer (April – September), averaging 2.8 days per year. Interannual variability in the frequency of gap-wind events is correlated with El Niño. During gap-wind events, the spatial scales of high off-shore directed winds ( $>10 \text{ m s}^{-1}$ ) reach almost 200 km off-shore and 225 km along the shelf break, suggesting that the winds directly influence both the shelf (20–65 km wide) and the off-shore waters. A model experiment suggests that a gap-wind event can result in eddy formation and changes in circulation and water properties. Increased entrainment of water from below the mixed layer due to the gap-wind event implies that mixed-layer nitrate concentrations could increase on the order of 5–10  $\mu\text{mole/l}$ , potentially enhancing primary production in the region. An accompanying paper discusses part II of our study (Ladd et al., 2016) focusing on gap-wind events in the western GOA around Kodiak Island.

Publication Date: October 2016

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<http://www.sciencedirect.com/science/article/pii/S0967064515002830>



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### *Gap winds and their effects on regional oceanography Part II: Kodiak Island, Alaska*

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

**C. Ladd, W. Cheng, S. Salo (OAR/PMEL)**

- The oceanographic response to gap winds may influence the survival of larval fishes

Frequent gap winds, defined here as offshore-directed flow channeled through mountain gaps, have been observed near Kodiak Island in the Gulf of Alaska (GOA). Gap winds from the Iliamna Lake gap were investigated using QuikSCAT wind data. The influence of these wind events on the regional ocean was examined using satellite and *in situ* data combined with Regional Ocean Modeling System (ROMS) model runs. Gap winds influence the entire shelf width ( $> 200$  km) northeast of Kodiak Island and extend an additional  $\sim 150$  km off-shelf. Due to strong gradients in the along-shelf direction, they can result in vertical velocities in the ocean of over  $20 \text{ m d}^{-1}$  due to Ekman pumping. The wind events also disrupt flow of the Alaska Coastal Current (ACC), resulting in decreased flow down Shelikof Strait and increased velocities on the outer shelf. This disruption of the ACC has implications for freshwater transport into the Bering Sea. The oceanographic response to gap winds may influence the survival of larval fishes as Arrowtooth Flounder recruitment is negatively correlated with the interannual frequency of gap-wind events, and Pacific Cod recruitment is positively correlated. The frequency of offshore directed winds exhibits a strong seasonal cycle averaging  $\sim 7$  days per month during winter and  $\sim 2$  days per month during summer. Interannual variability is correlated with the Pacific North America Index and shows a linear trend, increasing by 1.35 days per year. An accompanying paper discusses part I of our study (Ladd and Cheng, 2016) focusing on gap-wind events flowing out of Cross Sound in the eastern GOA.

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### *Temporal variability of reactive iron over the Gulf of Alaska Shelf*

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

A. M. Aguilar-Islas, M. J. M. Séguret, R. Rember, K. Buck, **P. Proctor, C. W. Mordy, N. B. Kachel (OAR/PMEL)**

- The authors studied the dissolved iron pool at the Gulf of Alaska front
- In spring, dissolved iron relative to available surface nitrate was in excess inshore, and deficient offshore.
- Compared to summer, surface dissolved iron accounted for a higher fraction of the total dissolved iron pool in Spring
- Organic iron-binding ligand data reveal excess concentrations of ligands in both spring and summer, indicating incomplete titration by iron.

The Gulf of Alaska (GoA) shelf is a highly productive regime bordering the nitrate-rich, iron (Fe)-limited waters of the central GoA. The exchange between nitrate-limited, Fe-replete coastal waters and nitrate-rich, Fe-deplete offshore waters, amplified by mesoscale eddies, is key to the productivity of the region. Previous summer field studies have observed the partitioning of Fe in the coastal GoA as being heavily dominated by the particulate phase due to the high suspended particulate loads carried by glacial rivers into these coastal waters. Here we present new physico-chemical iron data and nutrient data from the continental shelf of the GoA during spring and late summer 2011. The late summer data along the Seward Line showed variable surface dissolved iron (DFe) concentrations (0.052 nM offshore to 4.87 nM inshore), within the range of previous observations. Relative to available surface nitrate, DFe was in excess (at Fe:C=50  $\mu\text{mol}:\text{mol}$ ) inshore, and deficient (at Fe:C=20  $\mu\text{mol}:\text{mol}$ ) offshore. Summer surface total dissolvable iron (TDFe, acidified unfiltered samples) was dominated by the acid-labile particulate fraction over the shelf (with a median contribution of only 3% by DFe), supporting previously observed Fe partitioning in the GoA. In contrast, our spring data from southeast GoA showed TDFe differently partitioned, with surface DFe (0.28–4.91 nM) accounting on average for a much higher fraction (~25%) of the TDFe pool. Spring surface DFe was insufficient relative to available nitrate over much of the surveyed region (at Fe:C=50  $\mu\text{mol}:\text{mol}$ ). Organic Fe-binding ligand data reveal excess concentrations of ligands in both spring and summer, indicating incomplete titration by Fe. Excess concentrations of an especially strong-binding ligand class in spring surface waters may reflect in-situ ligand production. Due to anomalous spring conditions in 2011, river flow and phytoplankton biomass during our spring sampling were lower than the expected May average. We argue our samples are likely more representative of early spring





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pre-bloom conditions, providing an idea of the possible physico-chemical partitioning of Fe in coastal GoA waters relevant to initial spring bloom dynamics.

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<http://www.sciencedirect.com/science/article/pii/S0967064515001484>

*Long-term observations of Alaska Coastal Current in the northern Gulf of Alaska*  
Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

**P. J. Stabeno (OAR/PMEL), S. Bell, W. Cheng (OAR/PMEL), S. Danielson, N. B. Kachel (OAR/PMEL), C. W. Mordy (OAR/PMEL)**

Bullets

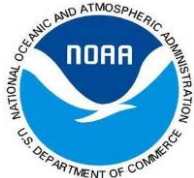
- Collected data from 30 year period of mooring buoys
- Transport was correlated with alongshore winds and was modified by river discharge at some sites
- Mixing may prolong the duration of elevated primary production during the summer

The Alaska Coastal Current is a continuous, well-defined system extending for ~1700 km along the coast of Alaska from Seward, Alaska to Samalga Pass in the Aleutian Islands. The currents in this region are examined using data collected at >20 mooring sites and from >400 satellite-tracked drifters. While not continuous, the mooring data span a 30 year period (1984–2014). Using current meter data collected at a dozen mooring sites spread over four lines (Seward, Gore Point, Kennedy and Stevenson Entrances, and the exit to Shelikof Strait) total transport was calculated. Transport was significantly correlated with alongshore winds, although the correlation at the Seward Line was weak. The largest mean transport in the Alaska Coastal Current occurred at Gore Point ( $1.4 \times 10^6 \text{ m}^3 \text{ s}^{-1}$  in winter and  $0.6 \times 10^6 \text{ m}^3 \text{ s}^{-1}$  in summer), with the transport at the exit to Shelikof Strait ( $1.3 \times 10^6 \text{ m}^3 \text{ s}^{-1}$  in winter and  $0.6 \times 10^6 \text{ m}^3 \text{ s}^{-1}$  in summer) only slightly less. The transport was modified at the Seward Line in late summer and fall by frontal undulations associated with strong river discharge that enters onto the shelf at that time of year. The interaction of the Alaska Coastal Current and tidal currents with shallow banks in the vicinity of Kodiak Archipelago and in Kennedy–Stevenson Entrance results in mixing and prolonged primary production throughout the summer.

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<http://www.sciencedirect.com/science/article/pii/S0967064516300613>



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### *Southeast Alaskan shelf from the southern tip of Baranof Island to Kayak Island: Currents, mixing and chlorophyll-a*

Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

**P. J. Staben** (OAR-PMEL), **N. A. Bond** (OAR-PMEL) , **N. B. Kachel** (OAR-PMEL), **C. Ladd** (OAR-PMEL), **C. W. Mordy** (OAR-PMEL), S. L. Strom

- This manuscript describes the coastal currents in southeastern Alaska and the processes that affect them
- Observations from 2011 to 2013 show bottom-up processes contributed to lower chlorophyll-a concentrations in 2011

During 2011 and 2013, an integrated ecosystem study was undertaken on the Southeast Alaska shelf and slope. As part of that study, a total of 8 moorings were deployed each year along the coast of Baranof and Chichagof Islands, in Cross Sound and at Icy Point. In addition, 18 satellite-tracked drifters were deployed during the two field years. The goals of this manuscript are to describe: the coastal currents in southeastern Alaska; the processes affecting them; and how the physics modify the nutrients and primary production in the region. Mixing in Cross Sound is an important source of nutrients for the shelf north of the sound, resulting in prolonged production during summer. While the Alaska Coastal Current is not a continuous feature along the entire Gulf of Alaska coast, it does exist from southern tip of Baranof Island to Cross Sound, and again northwest of Yakutat. The narrowness of this shelf coupled with the meanders and eddies in the Alaska Current result in large amounts of on-shelf flow of slope water and off-shelf flow of coastal water. While local currents and summer winds were similar in 2011 and 2013, 2011 was characterized by low chlorophyll-a concentrations throughout the spring–summer, while chlorophyll concentrations in 2013 were typical. The cause of this difference remains unclear, but bottom-up processes likely contributed to the low chlorophyll-a concentrations in 2011.

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<http://www.sciencedirect.com/science/article/pii/S0967064515002209>



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*A model-based examination of multivariate physical modes in the Gulf of Alaska*  
Deep Sea Research Part II: Topical Studies in Oceanography (2.763)

**A. J. Hermann (OAR/PMEL), C. Ladd (OAR/PMEL), W. Cheng (OAR/PMEL),** E. N. Curchitser, K. Hedstrom

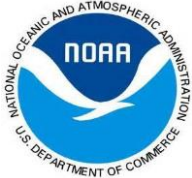
- Study examines trends in a time series of ocean conditions in the Gulf of Alaska
- The Pacific Decadal Oscillation and Multivariate El Nino account for 40% of the time series variations

We use multivariate output from a hydrodynamic model of the Gulf of Alaska (GOA) to explore the covariance among its physical state and air/sea fluxes. We attempt to summarize this coupled variability using a limited set of patterns, and examine their correlation to three large-scale climate indices relevant to the Northeast Pacific. This analysis is focused on perturbations from monthly climatology of the following attributes of the GOA: sea surface temperature, sea surface height, mixed layer depth, sea surface salinity, latent heat flux, sensible heat flux, shortwave irradiance, net long wave irradiance, currents at 40 m depth, and wind stress. We identified two multivariate modes, both substantially correlated with the Pacific Decadal Oscillation (PDO) and Multivariate El Nino (MEI) indices on interannual timescales, which together account for ~30% of the total normalized variance of the perturbation time series. These two modes indicate the following covarying events during periods of positive PDO/MEI: (1) anomalously warm, wet and windy conditions (typically in winter), with elevated coastal SSH, followed 2–5 months later by (2) reduced cloud cover, with emerging shelf-break eddies. Similar modes are found when the analysis is performed separately on the eastern and western GOA; in general, modal amplitudes appear stronger in the western GOA.

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<http://www.sciencedirect.com/science/article/pii/S0967064516300777>



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### *Spatial shifts in salmonine harvest, harvest rate, and effort by charter boat anglers in Lake Michigan, 1992–2012*

Journal of Great Lakes Research (1.77)

N. T. Simpson, A. Honsey, **E. S. Rutherford (OAR/GLERL)**, T. O. Höök

- A spatial distribution of salmonid species showed that fishing effort has shifted to occur more frequently closer to shore.
- Locations of heavy fishing have management implications for stocking decisions and harvest management.

Stocked and naturally reproducing salmonids in Lake Michigan support an economically important charter boat fishery which operates from multiple locations around the lake. Charter boat operators depend on the sustainability and spatial availability of salmonid species. We analyzed the spatial distributions of charter boat harvest of brown trout, Chinook salmon, coho salmon, lake trout, and rainbow trout from 1992 to 2012. We found that during this 21 year period fishing effort shifted closer to shore, to the west, and to the north. Harvest of some species, namely lake trout and rainbow trout, shifted towards shallower bottom depths and closer to shore. In contrast, harvests of Chinook and coho salmon have not shifted closer to shore in a consistent manner. We suggest that a variety of factors may have contributed to these trends in harvest patterns, including recent ecosystem shifts in Lake Michigan. While we acknowledge that spatial harvest patterns are unlikely to precisely mirror salmonid distribution patterns, we believe that reporting coarse shifts in harvest has implications for future management options including, but not limited to, stocking decisions and harvest regulations.

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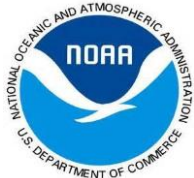
<http://www.sciencedirect.com/science/article/pii/S0380133016301277>

### *Vertical air motions and raindrop size distributions estimated using mean doppler velocity difference from 3- and 35-GHz vertically pointing radars*

IEEE Transactions of the Geoscience and Remote Sensing Society (2.228)

**C. R. Williams (OAR/ESRL)**, R. M. Beauchamp, V. Chandrasekar

- The measured radar velocity from vertically pointing radars is radar frequency dependent such that raindrops appear to fall slower at higher radar operating frequencies.
- Exploiting this dual-frequency radar electromagnetic wave propagation phenomena, a new technique was developed that estimates the raindrop size distribution and vertical velocity in the vertical column above the two radars.



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- Improved estimates of observed raindrop size distributions will lead to better model parameterization of rainfall microphysics and improved weather forecasts.

Vertical profiles of vertical air motion and raindrop size distributions (DSDs) within stratiform rain are estimated using two collocated vertically pointing radars (VPRs) operating at 3 and 35 GHz. Different raindrop backscattering cross sections occur at 3 and 35 GHz with Rayleigh scattering occurring for all raindrops at 3 GHz and Mie scattering occurring for larger raindrops at 35 GHz. This frequency-dependent backscattering cross section causes differently shaped reflectivity-weighted Doppler velocity spectra leading to radar transmit frequency-dependent radar moments of intrinsic reflectivity factor, mean Doppler velocity, and spectrum variance. The retrieval method described herein uses four radar moments as inputs to retrieve four outputs at each height within a precipitation column. The inputs include 3-GHz VPR mean Doppler velocity and unattenuated reflectivity factor and 35-GHz VPR mean Doppler velocity and spectrum variance. The outputs include vertical air motion and three parameters of a gamma-shaped DSD. To account for different VPR sample volumes, radar observations were accumulated over 45 s and over several range gates to represent time–space scales larger than either VPR sample volumes. Observed variability over this common time–space scale is used to estimate retrieval uncertainties. The retrieved air motions and DSD parameters compare well against retrievals from a collocated 449-MHz VPR that estimated air motions from Bragg scattering signals and DSD parameters from Rayleigh scattering signals.

Publication Date: October, 2016

Available Online: <http://ieeexplore.ieee.org/document/7505946/>

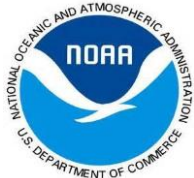
### *Deep and abyssal ocean warming from 35 years of repeat hydrography*

Geophysical Research Letters (4.99)

D. G. Desbruyères, S. G. Purkey, E. L. McDonagh, **G. C. Johnson (OAR/PMEL)**, B. A. King

- The strongest warming rates are found in the abyssal layer (4000–6000 m), which contributes to one-third of the total heat uptake with the largest contribution from the Southern and Pacific oceans.
- Global warming rate did not significantly change from the 1990s to the 2000s, but there was significant regional variability

Global and regional ocean warming deeper than 2000 m is investigated using 35 years of sustained repeat hydrographic survey data starting in 1981. The global



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long-term temperature trend below 2000 m, representing the time period 1991–2010, is equivalent to a mean heat flux of  $0.065 \pm 0.040 \text{ W m}^{-2}$  applied over the Earth's surface area. The strongest warming rates are found in the abyssal layer (4000–6000 m), which contributes to one-third of the total heat uptake with the largest contribution from the Southern and Pacific oceans. A similar regional pattern is found in the deep layer (2000–4000 m), which explains the remaining two-thirds of the total heat uptake yet with larger uncertainties. The global average warming rate did not change within uncertainties pre-2000 vs. post-2000, whereas ocean-average warming rates decreased in the Pacific and Indian oceans, and increased in the Atlantic and Southern oceans.

Publication Date: October 9, 2016

Available Online: <http://onlinelibrary.wiley.com/doi/10.1002/2016GL070413/full>